Three-quarter view preference for three-dimensional objects in 8-month-old infants

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This study examined infants' visual perception of three-dimensional common objects. It has been reported that human adults perceive object images in a view-dependent manner: three-quarter views are often preferred to other views, and the sensitivity to object orientation is lower for three-quarter views than for other views. We tested whether such characteristics were observed in 6- to 8-month-old infants by measuring their preferential looking behavior. In Experiment 1 we examined 190- to 240-day-olds' sensitivity to orientation change and in Experiment 2 we examined these infants' preferential looking for the three-quarter view. The 240-day-old infants showed a pattern of results similar to adults for some objects, while the 190-day-old infants did not. The 240-day-old infants' perception of object view is (partly) similar to that of adults. These results suggest that human visual perception of three-dimensional objects develops at 6 to 8 months of age.

Introduction

We instantly perceive and recognize objects through vision. Efficient visual object perception/recognition is one of the most essential functions of human visual cognition. It is founded on a highly complex mechanism that comprises multiple components solving various computationally challenging problems. Hence it is not surprising that this mechanism needs some time for postnatal development. Study on infant face perception has suggested that the maturation of face recognition performance requires several years (e.g., Crookes & McKone, 2009), even though it is well known that neonates often show face detection/recognition (e.g., de Heering et al., 2008; Macchi Cassia, Turati, & Simion, 2004). This is also the case for the perception/recognition of nonface three-dimensional objects; for instance, Smith (2009) argued that the style of visual object recognition changes between 18 and 24 months of age. Because visual object recognition involves multiple processing stages such as basic visual feature analysis, shape perception, and categorical perception, it develops gradually. However, the development of nonface object recognition has received limited attention by researchers. There is substantial evidence that the neural basis of nonface object perception can be dissociated from that of face perception (Germine, Cashdollar, Düzel, & Duchaine,

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2011; Kanwisher, McDermott, & Chun, 1997; but see Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999). It is still unclear how the nonface object perception/recognition mechanism matures and how long its maturation takes.

The first critical stage of object perception is organizing basic visual features into a "view," namely, a two-dimensional visuospatial representation of a three-dimensional object as seen from the observer's viewpoint. In most cases, a single object provides multiple views, such as a frontal view, a three-quarter view, and a profile view. The major theories of visual object recognition suppose view representation to be primitive input for the object recognition system. Tarr's (1995) multiple-views theory states that a representation of an object is a complex of multiple (but limited) views. Biederman's (1987) recognition-by-components theory assumes that object recognition is based on the analysis of a line-drawing description of the view. In most cases, a single view is not sufficient to reconstruct a perfect representation of a three-dimensional object, but it may contain some depth information, like Marr's (1982) 2 1/2 dimensional sketch. In this study, we focused on infants' perception of views.

Available evidence suggests that the ability to integrate various visual features into an object representation develops by 1 year of age (Needham, 2001; Wilcox, 1999). However, for adult-like view perception of three-dimensional objects, three-dimensional shape perception of objects is necessary. Interestingly, it has been suggested that the ability to perceive three-dimensional shapes develops very early, during 6 to 8 months of age. A study on infants' preference for object shapes from shading as assessed by a preferential reaching response showed that infants can discriminate convex shapes from concave shapes by 7 months of age (Granrud, Yonas, & Opland, 1985). This finding is consistent with findings on the development of perception from other pictorial depth cues such as familiar size (Yonas, Pettersen, & Granrud, 1982), occlusion (Granrud & Yonas, 1984), relative size (Yonas, Granrud, & Pettersen, 1985), texture gradients (Yonas, Granrud, Arterberry, & Hanson, 1986), and linear perspective (Arterberry, Yonas, & Bensen, 1989). Imura et al. (2008) showed that 7- to 8-month-old infants perceived pictorial depth cues defined by shading and line junction as well. Tsuruhara et al. (2010) support the hypothesis that the ability to form three-dimensional spatial representations of an object from pictorial depth cues emerges at about 6 to 7 months of age. These findings imply that view perception develops during 6 to 8 months of age.

Given the above findings, we hypothesized that by 8 months of age infants acquire the ability to process and integrate visual features critical for object perception and become ready to develop the mechanism for generating the view representations of three-dimensional objects. Soska and Johnson (2008) reported relevant findings. They indicated that by 6 months, infants can form a representation of a solid three-dimensional object after observing only two views of the object, suggesting adult-like object perception based on view perception. In their experiment, infants were habituated with two views (15° difference in orientation) of a wedge-like object, then tested with displays in which the object was rotated and was showed its full 360° view. At 6 months of age, infants showed a reliable novelty preference for the test display showing that the object was hollow. Thus, by 6 months, infants may achieve three-dimensional object perception by integrating limited views. Yet little is known about infants' object orientation perception. In addition, it is unclear whether infants show a preference for the three-quarter view of common objects, since Soska and Johnson's (2008) stimuli were nonsense novel objects. In the present study, we tested whether 6- to 8-month-old infants show view perception performance that is qualitatively equivalent to that of adults.

How do we study view perception? Some characteristics of view perception are known through experiments with adult participants. First, for many nonface familiar objects, the subjective goodness of view is higher for three-quarter views than other views (Niimi & Yokosawa, 2009; Palmer, Rosch, & Chase, 1981); namely, humans prefer three-quarter views to frontal views and profile views. This is because three-quarter views provide typical, easy-to-recognize views of familiar objects. Second, visual sensitivity to object orientation is dependent on the view (Niimi & Yokosawa, 2008, 2009); specifically, it is more difficult to detect a slight change of view (i.e., object orientation) from a three-quarter view than it is to detect the same change of view from frontal or profile views. For instance, using images of familiar objects such as a chair and a frog, Niimi and Yokosawa (2008) found that the reaction time to detect a 15° difference in object orientation was longer for a 30° versus 45° pair (i.e., three-quarter views) than for a 0° (front) versus 15° pair.

The question addressed in this paper is whether 6- to 8-month-old infants also show the above characteristics of view perception. Adults show worse detection of slight changes of view (i.e., object orientation) from a three-quarter view than detection of the same change of view from other views (e.g., frontal), and adults prefer the three-quarter view to other views. Experiment 1 tested infants' view sensitivity; namely, whether infants' detection of slight changes of view from a three-quarter view was worse than their detection of the same change of view from other views. Experiment 2 tested whether infants prefer the three-quarter view to other views. We compared the results between two groups, 190-day-old infants and 240-day-old infants.

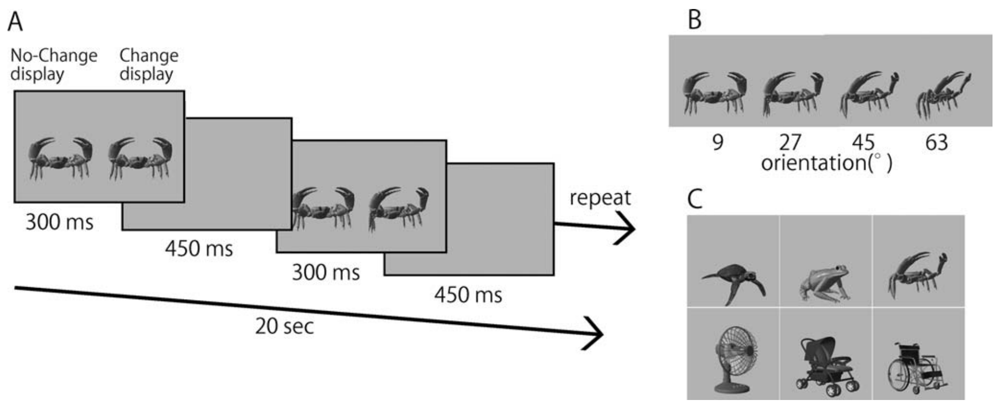

Figure 1. Illustration of the change-detection paradigm and stimuli used in all experiments. (A) Illustration of Change and No-change displays. Infants were presented with side-by-side streams, one in which the orientation did not change across cycles and one in which the orientation of images alternated across the flashes within a trial. (B) The four orientations. (C) Images of animal and artifact object.

Note that the purpose of this study was not to find evidence for the use of three-dimensional, structural-description representation of objects by infants. The current study seeks evidence for adult-like perception of views of three-dimensional objects, which signifies maturity of visual object perception. Recognition of three-dimensional objects may not require three-dimensional representation (Tarr, 1995), and view-dependent performance of object recognition does not necessarily mean the use of view-dependent representation (Bar, 2001). Hence, it was difficult to determine whether the representation used by the infants was three-dimensional, regardless of the results of Experiment 1 (test of view invariance) and Experiment 2 (test of view dependence in preference).

Experiment 1: Object orientation sensitivity

Niimi and Yokosawa (2009) examined adults' sensitivity to object orientation. The results showed that a 45° orientation (i.e., a three-quarter view) involved lower orientation sensitivity than a 9° orientation (a near-frontal view). We examined whether this is also the case for infants.

In Experiment 1, we adopted a change-detection paradigm. Infants were shown a screen of object image pairs (see Figure 1A). Two screens of object stimuli were continuously alternating, interleaved with a blank screen. On either side of the screen, an identical view of the object was displayed throughout; that is, there was no change in object orientation over the alternation (No-change display). On the other side of the screen, two different views of the object were displayed by alternation (Change display); that is, there was a change in object orientation. Since infants prefer changing displays (Oakes et al., 2006; Ross-Sheehy et al., 2003), it was expected that, if the infant perceived the orientation difference, the Change display would be looked at more. A single trial lasted for 20 s. The screens were repeatedly alternated for the duration. The object image pair was shown for 300 ms, interleaved with 450 ms of blank screen. In each trial, a single object identity was used.

To compare the infants' preference for change display among views, we adopted three standard orientations of object: 9°, 27°, and 45°, where 0° indicated the frontal orientation. In the No-change display, one of the standard orientations was adopted. In the Change display, the orientation of the No-change display and +18° orientation was used; for example, a 9° standard orientation was alternated with a 27° orientation. The 27° orientation was alternated with a 45° orientation, and the 45° orientation was alternated with a 63° orientation. Thereby, we compared the infants' Change display preference among the three standard orientations.

Methods

Participants

Participants consisted of forty-one 190-day-old infants (mean age = 189.7 days, range = 165–209 days, 17 females, 24 males) and forty-one 240-day-old infants (mean age = 235.0 days, range = 210–253 days, 21 females, 20 males). All were healthy infants who had a birth weight greater than 2500 g. An additional 21 infants were tested but excluded from the analysis due to fussiness (two), a side bias greater than 95% for one side of the screen (nine), or an insufficient total looking time (<12.0 s) in the two test trials (10). The participants were recruited using advertisements in newspapers.

Apparatus

All stimuli were displayed on a 22-in. cathode ray tube (CRT) monitor (Mitsubishi DP2070SB, NEC-Mitsubishi Electronics Display of America, Inc., Itasca, IL) controlled by a computer. The infant and the CRT monitor were located inside an enclosure that was made of an iron frame and cloth. Each infant sat on his or her parent's lap in front of the CRT monitor. The infant's viewing distance from the monitor was approximately 40 cm. There were two loudspeakers, one on either side of the CRT monitor. There was a charged-coupled device (CCD) camera (AVC-66ZNP, AVTECH Corporation, Taiwan) just below the monitor screen. Throughout the experiment, the infant's behavior was videotaped through this camera. The experimenter could observe the infant's behavior via a monitor connected to the CCD camera.

Stimuli

Because of the limitation of the number of stimuli presented to infant participants, we selected four orientations from the 10 orientations used in Niimi and Yokosawa's (2008, 2009) studies. The orientations were 9°, 27°, 45°, and 63° (Figure 1B), which showed a clear difference of sensitivity to object orientation in the studies. We also selected six objects (Figure 1C) from the 18 objects used in the previous studies. Since it is known that there are some differences between the recognition of natural objects, such as animals, and the recognition of artifacts, such as vehicles (Humphrey, Goodale, Jakobson, & Servos, 1994; Humphreys & Forde, 2001), we included both categories—three animals and three artifacts (Figure 1C). The six objects were selected because they have characteristics typical of orientation sensitivity. Based on Niimi and Yokosawa's (2009) data, for each of the 18 objects they used, an orientation sensitivity function (orientation sensitivity as a function of orientation) was calculated. Then, a correlation between the object's function and the orientation sensitivity function was derived from the data averaged over the 18 objects. We selected the three objects with the highest correlation from each category (animals/artifacts).

All stimulus images were in gray scale and displayed maximally in $8.8° \times 8.7°$ visual angle. The background was a homogeneous gray field.

Procedure

Each infant participated in six trials: two trials for each standard orientation (9°, 27°, and 45°). The two trials for each standard orientation were successively presented. For each infant, one object was selected from the six stimulus objects; then the object was shown for all six trials.

Prior to every trial, in order to attract the infant's attention, a fixation figure was shown at the center of the CRT monitor accompanied by a short beep sound. After confirming that the infant was looking at the fixation figure, the experimenter started the trial. In each trial, infants were shown two displays (Change/No-change display) side by side simultaneously (see Figure 1A). The object image pair was presented for 300 ms followed by a 450 ms blank screen. Then the second object image pair (one was a repetition of the standard orientation and another was at +18° orientation) was presented for 300 ms followed by a 450 ms blank screen. This sequence was continuously repeated for 20 s. To attract infants' attention, we presented a short sound at the onset of the image each time the image flashed. The side of the Change display was counterbalanced between the two trials per standard orientation. The side of the Change display in the first trial and the order of presentation of the three standard orientations were randomized across the infants.

Data coding and analysis

One observer, who was unaware of the stimulus images, measured the infants' fixations to the left and right sides of the display based on video recordings. Only the infants' looking behavior was visible in the video. Although the observer could not see the stimulus, he or she was aware of the timing of the beginning and the end of each trial from the beep sound that was presented at those times.

As an index of the relative amount of time looking at the Change display compared with the No-change display, a Change display preference score was calculated for each participant. This was given by dividing the participant's looking time for the Change display by their total looking time for either of the stimuli.

Results

Total looking times

To determine whether the standard orientation (9°, 27°, 45°), object category (animals/artifacts), and infants' age (190 days old/240 days old) affected the total looking time (Table 1), we conducted a three-way analysis of variance (ANOVA) for the total looking times: (1) standard orientation as a within-participants factor, (2) object category as a between-participants factor, and (3) age as a between-participants factor. We did not observe any significant main effect or interac-

	Object category: Animals						Object category: Artifacts					
The standard orientation	9°		27°		45°		9°		27°		45°	
190-day-olds	24.92	(1.44)	25.23	(1.38)	22.46	(1.23)	24.14	(1.16)	27.14	(1.22)	25.32	(1.30)
240-day-olds	23.90	(1.22)	25.56	(1.16)	24.27	(1.01)	26.01	(1.27)	25.96	(1.39)	25.74	(1.62)

Table 1. Looking time (seconds) and standard errors (in parentheses) during two trials.

tion [standard orientation: $F(2, 78) = 2.10$; object category: $F(1, 78) = 2.07$; age: $F(1, 78) = < 1$; standard orientation × object category: $F(2, 78) < 1$; object category × age: $F(1, 78) < 1$; standard orientation × age: $F(2, 78) < 1$; standard orientation × object category × age: $F(2, 78) = 1.27$; all *ns*].

Preferential looking behavior

The mean Change display preference score was calculated for each of six conditions (three standard orientations × two object categories) of each participant (Figure 2). Two-tailed *t* tests were conducted to test whether the mean score was significantly higher than the chance level (0.5). The 240-day-olds showed a preference score significantly higher than 0.5 under the 9° standard orientation condition with artifacts [$t(19) = 3.25$, $p < 0.01$, $d = 1.03$], whereas no significant difference of preference score was shown from 0.5 under any other condition [with artifacts: $t(19) = 0.66$ and $t(19) = 0.58$ for 27° and 45° standard orientations, respectively; with animals: $t(20) = 0.08$, $t(20) = 0.24$, and $t(20) = -0.51$ for 9°, 27°, and 45° standard orientations, respectively; all $p > 0.05$]. For the 190-day-olds, no difference from chance level was found in any condition [with artifacts: $t(20) = 1.57$, $t(20) = 1.24$, and $t(20) = 0.72$ for 9°, 27°, and 45° standard orientations, respectively; with animals: $t(19) = -0.11$, $t(19) = -1.36$, and $t(19) = -2.01$ for 9°, 27°, and 45° standard orientations, respectively; all $p > 0.05$].

In summary, the 240-day-old infants showed sensitivity to the 18° orientation difference, but only for the 9° standard orientation of artifact objects. We did not find any evidence that the 190-day-olds detected the 18° orientation difference. As we discussed in our Introduction, Niimi and Yokosawa's (2008, 2009) experiments with adult participants showed that the sensitivity to object orientation difference was higher for orientations around 0° (front). Therefore, the pattern of the present results for 240-day-old infants is similar to that of adults in that the infants showed significant sensitivity for the orientation difference from 9° but not for 27° or 45°.

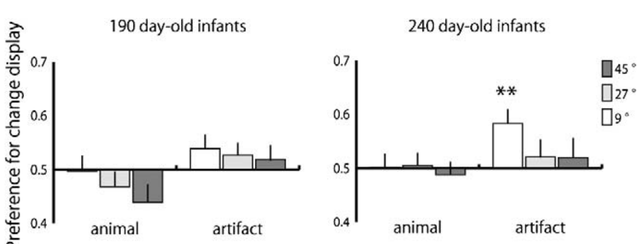

Figure 2. Results from Experiment 1. Mean time looking toward the Change display. Error bars show mean standard errors. ** $p < 0.01$ (two-tailed *t* tests).

Experiment 2: Subjective goodness of view

Niimi and Yokosawa (2009) have shown that the view goodness rated by adults was dependent on object orientation; the 27° and 45° orientations were rated better than the 9° orientation. The purpose of Experiment 2 was to test whether such preference for the three-quarter view would also be observed in infants. Since we are unable to ask infants to rate and report subjective goodness, here we measured the infants' preferential looking for the images of the objects in the three-quarter view. We presented a pair of object images in two orientation conditions: (1) 45° paired with a 9° orientation (9° vs. 45° condition) and (2) 45° paired with a 27° orientation (27° vs. 45° condition). We postulated that if infants have an adult-like characteristic of view goodness, they would prefer to look at an object in 45° orientation at the 9° versus 45° condition but not at the 27° versus 45° condition.

Methods

Participants

Participants consisted of forty 190-day-old infants (mean age = 189.3 days, range = 165–209 days, 23 females, 17 males) and forty-two 240-day-old infants (mean age = 234.2 days, range = 210–253 days, 25 females, 17 males). All were healthy Japanese infants who had a birth weight greater than 2500 g. An additional seven infants were tested but were excluded from the analysis due to fussiness (one), a side bias greater than 95% for one side of the screen (one), or insufficient total looking time (<9.0 s) in the two test

The orientation condition	Object category: Animals				Object category: Artifacts			
	9° vs. 45°		27° vs. 45°		9° vs. 45°		27° vs. 45°	
190-day-olds	17.36	(0.97)	16.57	(1.06)	20.67	(0.75)	20.23	(0.73)
240-day-olds	20.54	(1.08)	21.03	(2.09)	21.90	(0.90)	22.40	(0.96)

Table 2. Looking time (seconds) and standard errors (in parentheses) during two trials.

trials (five). The participants were recruited using advertisements in newspapers.

Apparatus

The apparatus used were identical to those in Experiment 1.

Stimuli

All six objects used in Experiment 1 (three animals and three artifacts) were also used in Experiment 2. We adopted the stimulus images of three orientations (9°, 27°, 45°) from the four orientations used in Experiment 1. According to the rated view goodness in Niimi and Yokosawa's (2009) study, the 9° orientation yielded a significantly lower rating than the other two orientations. The images were shown at the same size as in Experiment 1.

Procedure

Each infant participated in four trials, two trials for each of the two orientation conditions: the 9° versus 45° condition and the 27° versus 45° condition. The two trials for each orientation condition were presented successively. Each trial lasted for 15 s.

Prior to each trial, in order to attract the infant's attention, a fixation figure was shown in the center of the CRT monitor, accompanied by a short beep sound. After confirming that the infant was looking at the fixation figure, the experimenter started the trial.

In each trial, infants were shown two images simultaneously, which appeared on the screen side by side. An image of an object at 45° was shown on either side (left/right). Another image of the object, either at 9° or 27° object orientation (depending on the condition), was shown on the other side. The presentation time of the image pair was kept constant (15 s) for all the trials regardless of whether or not the infants looked at the stimulus. The side with the object image at 45° orientation was counterbalanced between the two trials per orientation condition. The side containing the object image at 45° orientation in the first trial and the presentation order of the two orientation conditions were randomized across the infants. Each infant observed only one object from the six objects we used. The assignments of object identity to infants were randomly determined so that each object was tested as equally as possible among infants.

Data coding and analysis

The method of data coding was the same as that in Experiment 1. As an index of the looking time for the object image at 45° orientation compared with other orientations (9° or 27°) we measured each infant's 45° preference. That is, we measured the proportion of each participant's looking time for the object image at a 45° orientation to their total looking time at either of the other object images.

Results

Total looking times

To determine whether the orientation condition (27° vs. 45° and 9° vs. 45°), object category (animals/artifacts), or infants' age (190 days old/240 days old) differentially affected the total looking time (Table 2), we conducted a three-way ANOVA for the total looking times, with orientation condition as a within-participants factor and object category and age as between-participants factors. The ANOVA revealed that the main effects of object category and age were significant [object category: $F(1, 78) = 8.06$, $p < 0.01$; age: $F(1, 78) = 10.43$, $p < 0.01$]. The artifacts yielded a longer looking time than the animals, and the 240-day-old infants looked at the stimuli longer than the 190-day-old infants. The main effect of orientation condition and any interaction were not significant.

Preferential looking behavior

As shown in Figure 3, for each age group, the mean 45° preference in each of four experimental conditions (orientation condition × object category) was analyzed. Two-tailed t tests were conducted to examine whether the mean 45° preference was significantly different from the chance level (0.5). We found significant difference in two cases: the 240-day-olds showed higher 45° preference in the 9° versus 45° condition of artifacts [$t(20) = 3.02$, $p < 0.01$, $d = 0.93$], and the 190-day-olds showed significantly lower 45° preference in the 27° versus 45° condition of animals [$t(19) = -2.71$, $p < 0.05$, $d = 0.86$].

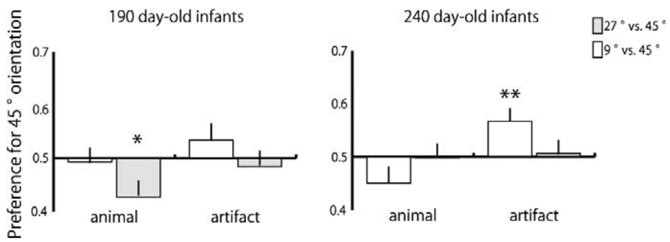

Figure 3. Results from Experiment 2. Mean time looking toward the 45° orientation. Error bars show mean standard errors. * $p < 0.05$, ** $p < 0.01$ (two-tailed t tests).

In no other condition did we find a 45° preference significantly different from 0.5. For the 240-day-olds, with artifacts, $t(20) = 0.29$ for the 27° versus 45° condition; with animals, $t(20) = -1.74$ and $t(20) = -0.10$ for the 9° versus 45° and 27° versus 45° conditions, respectively. For the 190-day-olds, with artifacts, $t(19) = 1.08$ and $t(19) = -0.57$ for the 9° versus 45° and 27° versus 45° conditions, respectively; with animals, $t(19) = -0.25$ for the 9° versus 45° condition.

In summary, the 240-day-old infants showed preference for three-quarter views (higher-than-chance 45° preference in the 9° versus 45° condition but not in the 27° versus 45° condition), though it was found only for artifact objects. The 190-day-old infants showed significant preference for 27° for animal objects, which was an unpredicted phenomenon. We address this point in the following discussion.

Discussion

The present study examined whether 165- to 254-day-old infants (6- to 8-month-old infants) have view perception of three-dimensional familiar objects in the same way as adults. We addressed the issue by examining infants' sensitivity to object orientation (Experiment 1) and view goodness (Experiment 2). As a result, we found evidence that the 8-month-old infants showed a pattern of view perception similar (at least partly) to that of adults, whereas the 6-month-old infants did not.

Experiment 1 showed that, for artifact objects, 240-day-old infants looked more to the Change display in the 9° condition. In other words, they detected the 18° orientation difference between the 9° view and the 27° view of artifact objects, but they did not detect the 18° difference between 27° and 45° or that between 45° and 63°. This result means that the 240-day-old infants' sensitivity to object orientation was relatively high for the 9° view and relatively low for three-quarter views (27° and 45°). This pattern of orientation sensitivity is consistent with that of adult results as reported by Niimi and Yokosawa (2008, 2009). More importantly, the same pattern of orientation sensitivity was not found for 190-day-old infants, who showed no evidence that they had detected the 18° orientation difference in any condition. These results of Experiment 1 suggest that the view perception of three-dimensional familiar objects emerges at 6 to 8 months of age. However, the observed performance of the 240-day-old infants in the task was limited; for instance, there was no significant difference for animals. Probably their view perception was still in the early stage of development.

Experiment 2 revealed that 240-day-old infants preferred the three-quarter view (only for artifacts) to the near-front view (9°), while 190-day-old infants did not. This result further supports the conclusion that an adult-like view perception of three-dimensional objects emerges at 6 to 8 months of age. However, it was also found that 190-day-old infants preferred the 27° view to the 45° view of animals, while 240-day-old infants did not show such preference. Although results with adult participants (Niimi & Yokosawa, 2009) showed that the mean view-goodness rating was highest at 27°, the difference of the 27° rating from the 45° rating was very small and not significant statistically. With the data at hand, it is difficult to conclude the reason why the infants preferred the 27° view to the 45° view of animals. However, the preference was observed in the 190-day-old infants but not in the 240-day-old infants. This finding further implies that the mechanism of view perception for three-dimensional objects changes in 6- to 8-month-olds. Further examination with younger infants in future study is critical for understanding this issue.

Another intriguing result of the experiments reported here was the effect of object category. In Experiment 1, the 240-day-old infants detected the 18° difference only for artifacts. In Experiment 2, the pattern of view preference was dependent on object category. Experiment 2 also demonstrated that the total looking time was longer for artifacts than animals. These results clearly demonstrated that object category did matter in infants' object perception. One possible account for the effect of category was the difference of visual features contained in the images of the objects. For instance, the images of artifacts may contain more straight contours than the images of animals. Actually, such difference was reported to be one of the factors affecting view perception (Niimi & Yokosawa, 2008). It seems plausible that in Experiment 1 the 240-day-old infants detected the orientation difference only for artifacts because straight, linear contour was a good clue for detecting differences in object orientation. It is also possible that the presence of the animals' faces caused the effect of category. As we have reviewed in our Introduction, infants are sensitive to faces and face-like visual stimuli (de Heering et al., 2008; Macchi Cassia et al., 2004).

One might assume that the effect of object category was due to a difference in familiarity. For instance, the artifact category contained a baby buggy, which might be familiar to the infants. It is known that familiarity affects object recognition (e.g., Bülthoff & Edelman, 1992). Through an additional questionnaire, we estimated infants' familiarity with the six stimulus objects we used in our experiments. We asked the mothers or fathers of infants who didn't participate in Experiment 1 and Experiment 2 to rate the familiarity of the six stimulus objects for their own infants in everyday life. The parents answered the question "How often does your infant see the object?" using 3-point scale (1 = have never seen, 2 = may have seen, 3 = have seen). The rated scores showed that the artifacts were rated significantly higher than the animals [two-tailed paired t tests; mean rated score 2.59 for artifacts and 1.28 for animals; $t(30) = 17.33$, $p < 0.0001$)], suggesting that the artifacts were familiar and the animals were unfamiliar to the infants. This may be the reason why the adult-like pattern of result was found only for artifacts—the mechanism of view perception may develop faster for familiar objects than for unfamiliar objects. These results suggest the possibility that the daily experience of seeing an object might play a crucial role in the development of the perception of that object.

In Experiment 2, infants showed preference for the 45° view. This might be affected by physical properties such as variation in contrast, symmetry, or contour variation. We examined whether these physical properties were related to infants' preference for the 45° view.

First, we checked the influence of the variation in contrast on infants' preference. We calculated the root mean square (RMS) contrasts for all stimulus images of three orientations (9°, 27°, 45°). To compare these differences among the orientations, we conducted a one-way ANOVA. The ANOVA did not show any difference in the RMS contrast among orientations [$F(2, 15) = 0.018$, $p = 0.982$]. This suggests that the significant preference for the 45° view was not due to the variation in contrast.

Second, we checked the influence of the symmetry on infants' preference. According to Bornstein, Ferdinandsen, and Gross's (1981) study, infants begin to show preferences for vertical symmetry by 4 months of age. All of our stimuli were images of symmetric objects; their 0° (i.e., frontal orientation) had symmetric contours. The symmetry of the contours degraded according to orientation changes from the frontal orientation. This means that the symmetry of the contours at the 45° view was lower than that at the 9° view. If infants showed preference for an image with the same symmetric property, such as that in the study by Bornstein et al., infants would prefer the 9° view to the 45° view, but results showed that they did not. This suggests that our results were not due to the symmetry.

Third, we examined the influence of the object's contour variation on infants' preference. To examine it, we used linearity rating scores (Niimi & Yokosawa, 2008) and compared the linearity of contours in our objects. Higher-scoring objects had significant preference for the 45° view and lower-scoring objects had lower preference for the 45° view in infants. This suggests that preference for the 45° view might be related to contour variation.

In conclusion, we found that view perception of three-dimensional objects develops at 6 to 8 months of age. In ways similar to adults, the 240-day-old infants showed higher orientation sensitivity to a near-frontal view than to the three-quarter view (Experiment 1) and showed preference for the three-quarter view rather than the near-frontal view (Experiment 2). On the other hand, the 190-day-old infants showed a different pattern of results. As Soska and Johnson (2008) reported, three-dimensional object perception based on view perception develops by 6 months. Therefore, the 6- to 8-month-olds in our experiments could already perceive the stimulus images as views of three-dimensional objects. We examined whether these infants' view perception differed between the three-quarter view and other views as adults' view perception does. It has been shown that, around 7 to 8 months of age, infants become able to perceive various attributes of objects and surfaces such as shape from shading (7 months: Granrud et al., 1985; Imura et al., 2008; Tsuruhara et al., 2009), motion from shadows (7 months: Imura et al., 2006; Yonas & Granrud, 2006), occlusion (4–6 months: Craton, 1996; Kellman & Spelke, 1983), and transparency (4–7 months: Johnson & Aslin, 2000; Otsuka et al., 2008). By 8 months of age, on average, infants become able to process the basic visual features essential for object perception and integrate them into a representation of object view. However, it seems arguable that the current finding is also a case for face perception. Our stimuli included animal objects, which have faces. Preference for face and face-like visual stimuli has been shown for infants (de Heering et al., 2008; Macchi Cassia et al., 2004). Furthermore, it has been reported that 2- to 4-month-old infants (Gliga & Dahene-Lambertz, 2007; Pascalis, de Haan, Nelson, & de Schonen, 1998) and even neonates (Turati, Bulf, & Simion, 2008) can discriminate views of the human head and recognize faces in a (partly) view-invariant way. Such view invariance of face recognition seems very different from our results on nonface objects. The mechanism for nonface object perception/recognition may develop more slowly than the mechanism for face perception/recognition.

Keywords: object perception, object view, development, three-quarter view, object orientation, canonical view, nonface object

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